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**Liang et al.**

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(54) **FIN-SHAPED STRUCTURE FORMING PROCESS**

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CPC ..... **H01L 21/31144** (2013.01)

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USPC ..... 438/703  
See application file for complete search history.

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*Primary Examiner* — Charles Garber

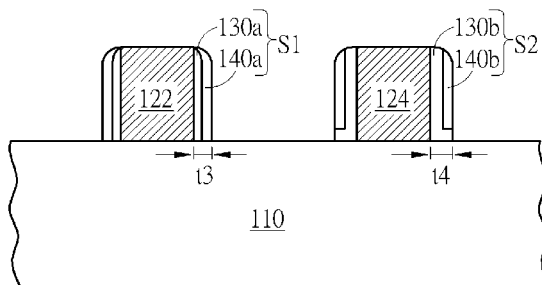
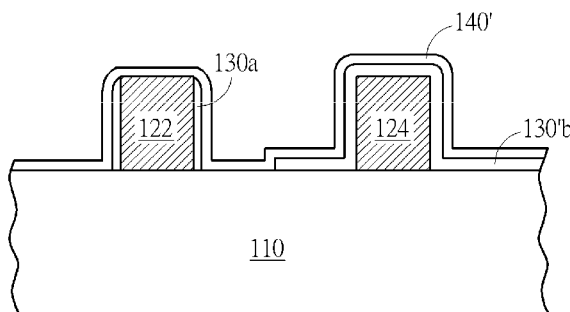
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(57) **ABSTRACT**

A fin-shaped structure forming process includes the following step. A first mandrel and a second mandrel are formed on a substrate. A first spacer material is formed to entirely cover the first mandrel, the second mandrel and the substrate. The exposed first spacer material is etched to form a first spacer on the substrate beside the first mandrel. A second spacer material is formed to entirely cover the first mandrel, the second mandrel and the substrate. The second spacer material and the first spacer material are etched to form a second spacer on the substrate beside the second mandrel and a third spacer including the first spacer on the substrate beside the first mandrel. The layout of the second spacer and the third spacer is transferred to the substrate, so a second fin-shaped structure and a first fin-shaped structure having different widths are formed respectively.

**14 Claims, 5 Drawing Sheets**



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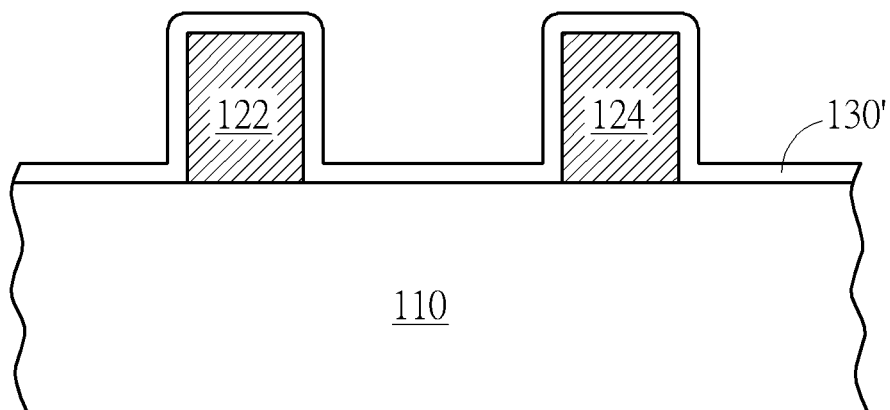


FIG. 1

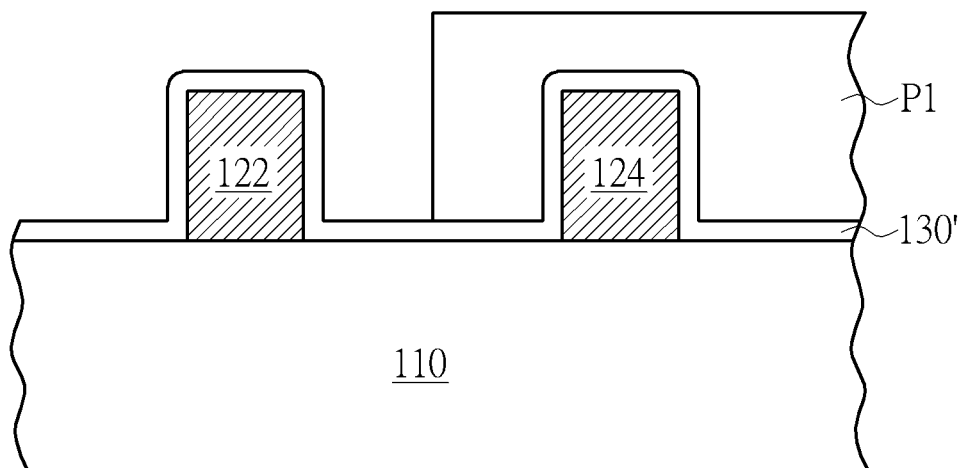


FIG. 2

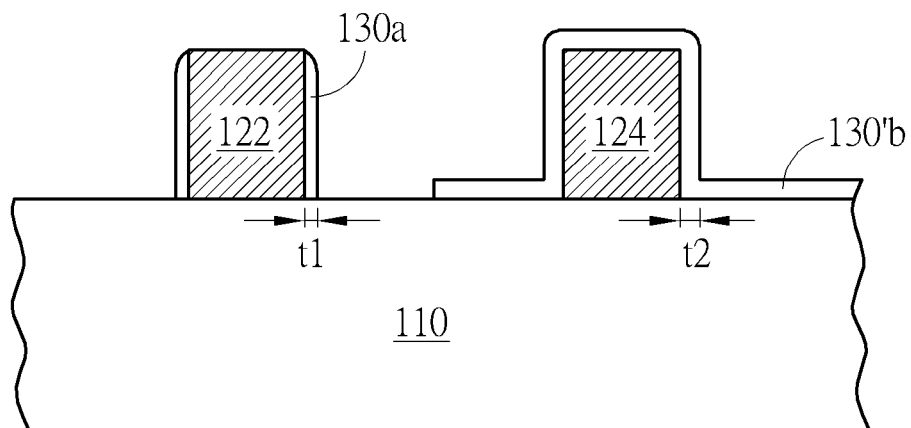


FIG. 3

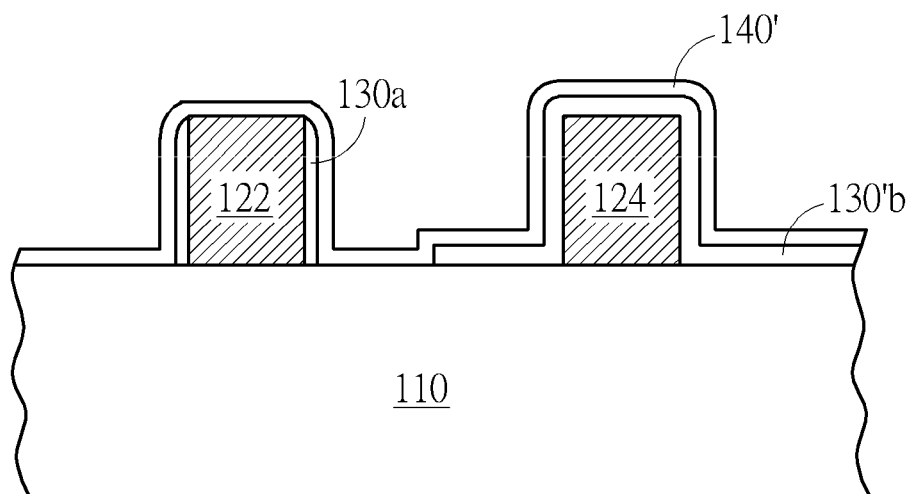


FIG. 4

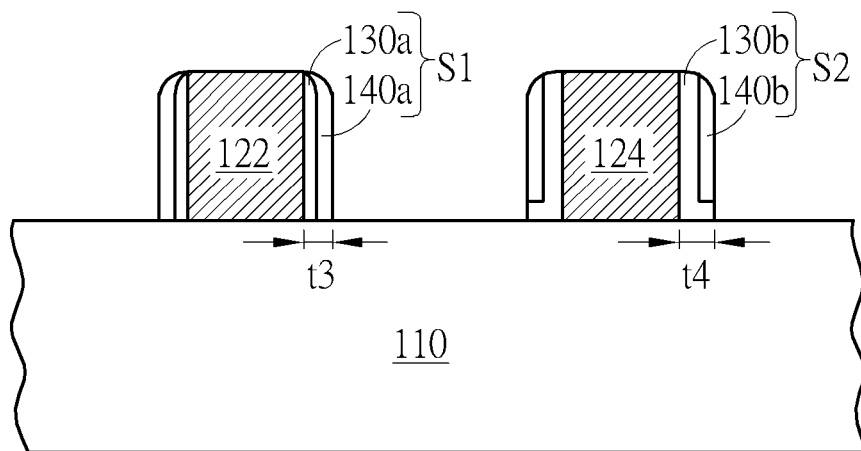


FIG. 5

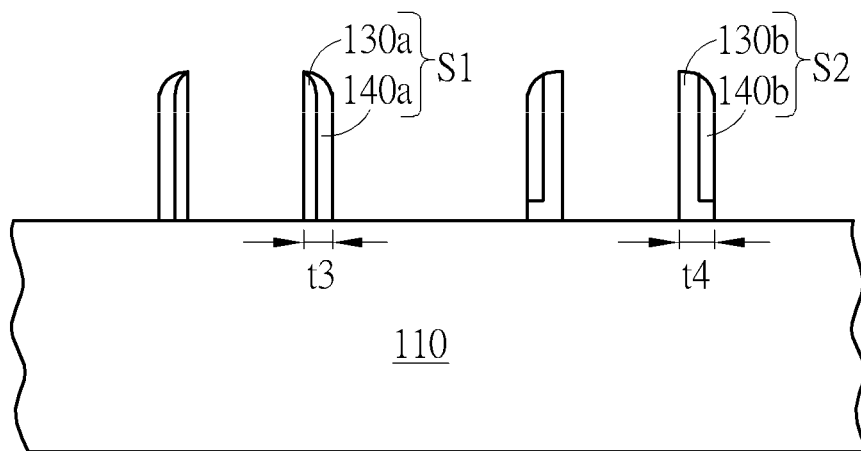


FIG. 6

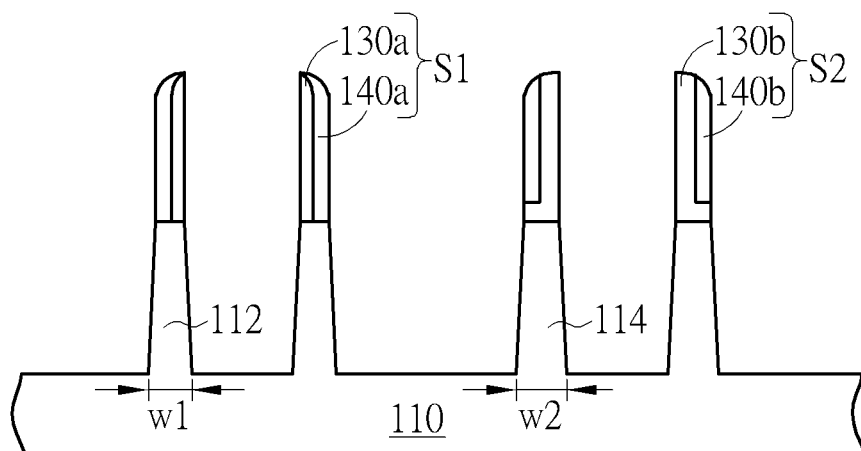


FIG. 7

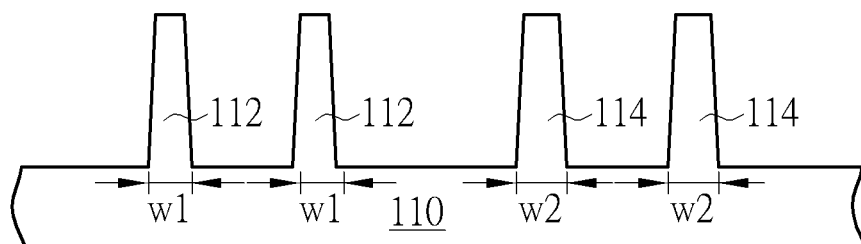


FIG. 8

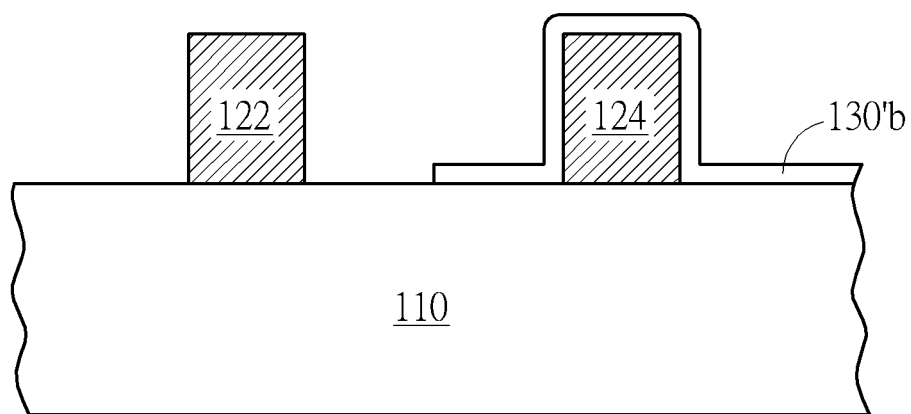


FIG. 9

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## FIN-SHAPED STRUCTURE FORMING PROCESS

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates generally to a fin-shaped structure forming process, and more specifically to a fin-shaped structure forming process that forms fin-shaped structures having different widths.

#### 2. Description of the Prior Art

Field effect transistors are important electronic devices in the fabrication of integrated circuits, and as the size of the semiconductor devices becomes smaller and smaller, the fabrication of the transistors also has to improve and is constantly enhanced to fabricate transistors with smaller sizes and higher quality.

With the increasing miniaturization of the semiconductor devices, various multi-gate MOSFET devices have been developed. The multi-gate MOSFET is advantageous for the following reasons. First, the manufacturing processes of the multi-gate MOSFET devices can be integrated into the traditional logic device processes, and thus are more compatible. In addition, since the three-dimensional structure of the multi-gate MOSFET increases the overlapping area between the gate and the substrate, the channel region is controlled more effectively. This therefore reduces the drain-induced barrier lowering (DIBL) effect and the short channel effect. Moreover, the channel region is longer for the same gate length. Therefore, the current between the source and the drain is increased. More precisely, a multi-gate MOSFET device includes fin-shaped structures on a substrate for gates or shallow trench isolation structures (STI) to be covered thereon, so that the gates or shallow trench isolation structures and the fin-shaped structures have multi-interfaces for forming gate channels or shallow trench isolation structures, and the widths and the lengths of the multi-interfaces decide the widths and the lengths of the gate channels, thus fin-shaped structures with different widths may be needed to achieve different purposes of multi-gate MOSFETs.

### SUMMARY OF THE INVENTION

The present invention provides a fin-shaped structure forming process, which forms fin-shaped structures with different widths by transferring the layout of spacers having different thicknesses.

The present invention provides a fin-shaped structure forming process including the following steps. A first mandrel and a second mandrel are formed on a substrate. A first spacer material is formed to entirely cover the first mandrel, the second mandrel and the substrate. A patterned material is formed to cover the second mandrel while exposing the first mandrel. The exposed first spacer material is etched to form a first spacer on the substrate beside the first mandrel. The patterned material is removed. A second spacer material is formed to entirely cover the first mandrel, the second mandrel and the substrate. The second spacer material and the first spacer material are etched to form a second spacer on the substrate beside the second mandrel and a third spacer including the first spacer on the substrate beside the first mandrel. The layout of the second spacer and the third spacer is transferred to the substrate, so that a second fin-shaped structure and a first fin-shaped structure having different widths are formed respectively.

According to the above, the present invention provides a fin-shaped structure forming process, which forms multi-

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spacers having different thicknesses and then transfers the layout of the multi-spacers to the substrate, so fin-shaped structures are formed, wherein the multi-spacers having different thicknesses may be formed by partially removing spacer materials through etching using materials such as photoresists.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1-8 schematically depict cross-sectional views of a fin-shaped structure forming process according to an embodiment of the present invention.

FIG. 9 schematically depicts a cross-sectional view of a fin-shaped structure forming process according to another embodiment of the present invention.

### DETAILED DESCRIPTION

FIGS. 1-8 schematically depict cross-sectional views of a fin-shaped structure forming process according to an embodiment of the present invention. As shown in FIG. 1, a substrate 110 is provided. The substrate 110 may be a semiconductor substrate such as a silicon substrate, a silicon containing substrate, a III-V group-on-silicon (such as GaN-on-silicon) substrate, a graphene-on-silicon substrate or a silicon-on-insulator (SOI) substrate.

A first mandrel 122 and a second mandrel 124 are formed on the substrate 110. The first mandrel 122 or/and the second mandrel 124 may be a single layer or multi layers composed of one or more than one materials, depending upon the needs. The first mandrel 122 or/and the second mandrel 124 may be a photoresist, polysilicon or hard mask layer(s), but it is not limited thereto. In one case, when the first mandrel 122 and the second mandrel 124 are polysilicon, they may be formed through the following step. A polysilicon layer entirely covers the substrate 110, and then the polysilicon layer is patterned by a photolithography process to form the first mandrel 122 and the second mandrel 124. In another case, when the first mandrel 122 and the second mandrel 124 are photoresists, they may be formed through the following step. A photoresist layer is formed and patterned to form two photoresists on the substrate 110, and a thermal process may be performed on the two photoresists to solidify the two photoresists, so the first mandrel 122 and the second mandrel 124 are formed. Thereafter, if different sizes for the first mandrel 122 and the second mandrel 124 or smaller sizes of at least one of the first mandrel 122 or the second mandrel 124 are required, a trimming process (not shown) can be performed to trim the first mandrel 122 or/and the second mandrel 124, wherein the trimming process may be a dry etching process, but it is not limited thereto.

Then, a first spacer material 130' is formed to entirely cover the first mandrel 122, the second mandrel 124 and the substrate 110. The first spacer material 130' may be nitride, but it is not limited thereto.

As shown in FIGS. 2-3, a first spacer 130a is formed on the substrate 110 on the sides the first mandrel 122 while a first spacer material 130'b covering the second mandrel 124 and the substrate 110 is reserved. More precisely, as shown in FIG. 2, a material (not shown) entirely covers the first mandrel 122, the second mandrel 124 and the substrate 110, and then the material is patterned to form a patterned material P1

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covering the second mandrel **124** while exposing the first mandrel **122**. In this embodiment, the material is a photoresist; in another embodiment, the material may be another light sensitive material, depending upon the needs. Thereafter, the exposed first spacer material **130'** is etched to form a first spacer **130a** on the substrate **110** on the sides of the first mandrel **122**, as shown in FIG. 3. Then, the patterned material **P1** is removed. Since the first spacer **130a** has been formed by etching the first spacer material **130'**, the thickness **t1** of the first spacer **130a** preferably is thinner than the thickness **t2** of the first spacer material **130'b**. The thickness difference between the first spacer **130a** and the first spacer material **130'b** can lead to the thickness difference of later formed spacers, the patterns of which will be transferred to the substrate **110** to form fin-shaped structures with different widths. In one case, the thickness **t1** of the first spacer **130a** is substantially zero, so as to approach a maximum thickness difference of the later formed spacers, as shown in FIG. 9. Furthermore, in some cases, such as the thickness **t1** of the first spacer **130a** approaches a minimum feature thickness, a trimming process may be performed to trim the first spacer **130a** to have a thickness smaller than the thickness **t1**, so that a refined structure can be formed. The trimming process may be a dry etching process but not limited thereto.

In this embodiment, the steps of FIGS. 1-3, i.e. a first spacer material **130'** is formed to entirely cover the first mandrel **122**, the second mandrel **124** and the substrate **110**; a patterned material **P1** is formed to cover the second mandrel **124** while exposing the first mandrel **122**; the exposed first spacer material **130'** is etched to form a first spacer **130a** on the substrate **110** on the sides of the first mandrel **122** while the first spacer material **130'b** covering the second mandrel **124** is reserved; and the patterned material **P1** is removed, are just performed once. In another embodiment, the steps of FIGS. 1-3 may be performed more than once, to form a stacked spacer (not shown) on the substrate **110** on the sides of the first mandrel **122** and a stacked layer (not shown) covering the second mandrel **124**. Moreover, the first spacer material **130'** may include a multilayer, which may be formed by performing depositing processes many times, but it is not limited thereto.

As shown in FIGS. 4-5, a second spacer **S2** and a third spacer **S1** with different thicknesses **t4** and **t3** are formed on the substrate **110** on the sides of the second mandrel **124** and the first mandrel **122** respectively. More precisely, as shown in FIG. 4, a second spacer material **140'** is formed to entirely cover the first mandrel **122**, the second mandrel **124** and the substrate **110**. That is, the second spacer material **140'** covers the first mandrel **122**, the first spacer **130a**, the second mandrel **124** and the first spacer material **130'b**. The second spacer material **140'** may be nitride, but it is not limited thereto. Then, the second spacer material **140'** and the first spacer material **130'b** covering the second mandrel **124** are etched to form a second spacer **S2** including an external spacer **140b** and an inner spacer **130b** on the substrate **110** on the sides of the second mandrel **124**, while the second spacer material **140'** covering the first mandrel **122** is etched to form an external spacer **140a**, such that a third spacer **S1** is constituted by the first spacer **130a** and the external spacer **140a**, as shown in FIG. 5.

It is emphasized that the thickness of the third spacer **S1** must be different from the thickness **t4** of the second spacer **S2**, so that later formed fin-shaped structures with different widths can be obtained. In this embodiment, since the first spacer material **130'** is etched to form the first spacer **130a** without the first spacer material **130'** covering the second mandrel **124** being etched at the same time, and since the third

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spacer **S1** is formed by etching twice the first spacer material **130'** and the second spacer material **140'** respectively while the second spacer **S2** is formed by only etching once the first spacer material **130'** and the second spacer material **140'** together, the thickness of the third spacer **S1** is therefore thinner than the thickness **t4** of the second spacer **S2**, so later formed fin-shaped structures with different widths can be achieved. Besides, the third spacer **S1** includes the first spacer **130a** and the external spacer **140a** having pillar-shapes, while the second spacer **S2** includes the inner spacer **130b** having an L-shaped cross-sectional profile and the external spacer **140b** having a pillar-shape. Or, the third spacer **S1** merely includes the external spacer **140a** having pillar-shapes while the second spacer **S2** includes the inner spacer **130b** having an L-shaped cross-sectional profile and the external spacer **140b** having a pillar-shape, like in the embodiment shown in FIG. 9.

In some cases, such as when the thickness **t3** or **t4** approaches a minimum feature thickness, a trimming process may be performed to trim the third spacer **S1** or the second spacer **S2** to have a thickness smaller than the thickness **t3** or **t4**, thereby obtaining a more refined structure. The trimming process may be a dry etching process, but it is not limited thereto.

As shown in FIGS. 6-8, the layout of the second spacer **S2** and the third spacer **S1** is transferred to the substrate **110**, so second fin-shaped structures **114** and first fin-shaped structures **112** having different widths **w2** and **w1** are respectively formed. More precisely, the first mandrel **122** and the second mandrel **124** are removed, as shown in FIG. 6. As shown in FIG. 7, the layout of the second spacer **S2** and the third spacer **S1** is transferred to the substrate **110** by methods such as etching, so that the second fin-shaped structures **114** and the first fin-shaped structures **112** are formed right below the second spacer **S2** and the third spacer **S1**. Then, the second spacer **S2** and the third spacer **S1** are removed, as shown in FIG. 8. This means that the substrate **110** having second fin-shaped structures **114** and the first fin-shaped structures **112** with different widths **w2** and **w1** are formed, wherein the width **w1** of the first fin-shaped structures **112** is smaller than the width **w2** of the second fin-shaped structures **114** because of the thickness **t3** of the third spacer **S1** being thinner than the thickness **t4** of the second spacer **S2**. Thereafter, a trimming process may be further performed on the first fin-shaped structures **112** or/and the second fin-shaped structures **114** to further achieve the first fin-shaped structures or/and the second fin-shaped structures having smaller and desired thicknesses, but it is not limited thereto. Other processes may be performed to improve the structure or the performance thereof.

In a preferred embodiment, the first spacer material **130'** and the second spacer material **140'** include different materials. For example, the first spacer material **130'** covered by the second spacer material **140'** can be composed by a material having higher etching rate than that of the second spacer material **140'** for the first spacer material **130'** being etched easily while the material of the second spacer material **140'** is hard enough to serve as a hard mask to each substrate **110**, thereby decreasing costs and increasing performances, but it is not limited thereto.

To summarize, the present invention provides a fin-shaped structure forming process, which forms multi-spacers having different thicknesses and then transfers the layout of the multi-spacers to the substrate, so that fin-shaped structures are formed, wherein the multi-spacers having different thicknesses may be formed by partially removing spacer materials through etching using materials such as photoresists. For

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example, a first mandrel and a second mandrel are formed on a substrate; a first spacer material is entirely covered; a patterned material is formed to cover the second mandrel while exposing the first mandrel; the exposed first spacer material is etched to form a first spacer on the substrate beside the first mandrel and then the patterned material is removed. The aforesaid steps may be formed repeatedly. Then, a second spacer material is entirely covered; the second spacer material and the first spacer material are etched to form a second spacer on the substrate beside the second mandrel and a third spacer including the first spacer on the substrate beside the first mandrel; the layout of the second spacer and the third spacer is transferred to the substrate, so fin-shaped structures having different widths are formed.

Moreover, trimming processes may be further performed to trim the mandrels, the spacers or the fin-shaped structures to achieve desired sizes, especially when the sizes of these components approach minimum feature thicknesses. The mandrels may be photoresists or polysilicon, depending upon the needs.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A fin-shaped structure forming process, comprising:  
forming a first mandrel and a second mandrel on a substrate;  
(a) forming a first spacer material to entirely cover the first mandrel, the second mandrel and the substrate;  
(b) forming a patterned material to cover the second mandrel while exposing the first mandrel;  
(c) etching the exposed first spacer material to form a first spacer on the substrate on the sides of the first mandrel;  
(d) removing the patterned material;  
(e) forming a second spacer material to entirely cover the first mandrel, the second mandrel and the substrate;  
(f) etching the second spacer material and the first spacer material to form a second spacer on the substrate on the sides of the second mandrel and a third spacer comprising the first spacer on the substrate on the sides of the first mandrel; and  
(g) transferring the layout of the second spacer and the third spacer to the substrate, so a second fin-shaped structure and a first fin-shaped structure having different widths are respectively formed.

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2. The fin-shaped structure forming process according to claim 1, wherein at least one of the first mandrel and the second mandrel comprises a photoresist or a polysilicon gate.

3. The fin-shaped structure forming process according to claim 2, further comprising:

performing a thermal process to the first mandrel and the second mandrel after the first mandrel and the second mandrel are formed by photoresists.

4. The fin-shaped structure forming process according to claim 1, wherein the first mandrel or the second mandrel is trimmed by a trimming process.

5. The fin-shaped structure forming process according to claim 4, wherein the trimming process comprises a dry etching process.

6. The fin-shaped structure forming process according to claim 1, wherein the first spacer material and the second spacer material comprise different materials.

7. The fin-shaped structure forming process according to claim 1, wherein the first spacer material has a higher etching rate than the second spacer material.

8. The fin-shaped structure forming process according to claim 7, wherein the first spacer material and the second spacer material comprise nitride.

9. The fin-shaped structure forming process according to claim 1, wherein the thickness of the first spacer is thinner than the thickness of the first spacer material.

10. The fin-shaped structure forming process according to claim 9, wherein the thickness of the first spacer is substantially zero.

11. The fin-shaped structure forming process according to claim 1, wherein the steps of (a), (b), (c) and (d) are performed more than one time, and then the steps of (e), (f) and (g) are sequentially performed.

12. The fin-shaped structure forming process according to claim 1, wherein the thickness of the third spacer is thinner than the thickness of the second spacer.

13. The fin-shaped structure forming process according to claim 1, further comprising:

performing a trimming process after the first spacer is formed to trim the first spacer.

14. The fin-shaped structure forming process according to claim 1, further comprising:

performing a trimming process after the second spacer and the third spacer are formed to trim at least one of the second spacer and the third spacer.

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